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AN EXAMINATION OF SOME B003 DATA

by

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Introduction

The Air Force, Navy and Army have for many years employed spectrometric analysis of used lubricating oil as an aid in tracking the servicability of many types of equipment. Virtually all types of equipment with oil-wetted surfaces are covered by this (tri-service) Joint Oil Analysis Program (JOAP). As an oil-wetted surface wears, it is possible that small amounts of the metals contacted will be suspended in the oil medium. Thus, if the lubricating oil is periodically submitted to a spectrometric analysis, the resulting traces of metallic contaminants may be expected to provide information about the amount of wear suffered. Each type of equipment monitored by the program has a specified rate at which sampling is accomplished, typically based on the number of hours of use or on the number of miles travelled.

The spectrometric laboratories which process these used-oil samples are generally located at military bases, in proximity to the equipments being monitored, although a few civilian laboratories are also employed in the program. Personnel employed in spectrometer operation, and interpretation of the resulting analyses, are trained in specialized schools dedicated to JOAP applications. The JOAP Laboratory Manual [1] provides detailed instructions for all participating laboratories, describing sampling methods for obtaining used engine oil, spectrometer setup and operation, tables of acceptable levels and changes in levels of monitored contaminants for specific equipment codes (for both atomic emission and absorption instruments for Air Force engines), recording of data results, and twice-monthly forwarding of all JOAP analyses to the San Antonio Air Logistic Center (SA-ALC), Kelly Air Force Base, Texas. Participating laboratories must be certified, and maintain certification, through the monthly JOAP correlation program, also described in the JOAP Laboratory Manual.

The data bank of JOAP analyses at SA-ALC is available for management summary reports, either service-wide or for individual commands, and serves as a historical record of previous oil analysis records for the whole program. This report describes an investigation of some of the data submitted to this data bank during fiscal year 1988.

Two major points are addressed in this study; the first of these is concerned with the normal, marginal, high and abnormal ranges for the various wear metals, published in the JOAP Laboratory Manual, for different type of equipment codes (*TEC*s) (separate sets of ranges for the two different spectrometer types). These ranges are used by laboratory personnel to decide whether the results of the spectrometric analysis of the used engine oil indicates the need for some special action, such as more frequent sampling (because a problem may be developing) or possibly even grounding of the equipment if it appears that some type of failure may be imminent. So long as the current reading for a given wear metal remains in the normal zone, no special action is called for, based on the oil analysis; if a reading is found in the other zones (marginal through abnormal, in order of increasing concentration) special recommendations are outlined in the manual. The values of these ranges drive the frequency with which special actions may be required, with lower ranges necessarily causing increased frequency of recommendations for special actions. This study investigates the consistency of these normal, marginal, high and abnormal ranges across Air Force engine types, to the extent possible, employing historic records made available from the data repository at SA-ALC.

The second point addressed in this report is the discussion of a unified approach to defining these normal, marginal, abnormal and high ranges; these ranges are presently set by individual Air Force engine managers who may be employing quite different rationales and procedures in determining their values. There does not currently appear to be any general set of guidelines or recommendations for setting these ranges; this report discusses this problem and recommends some specific procedures in setting, and reviewing, these ranges.

Data Available

The Air Force supplied two magnetic tapes of data for this study, containing Air Force Oil Analysis data for the processing months of October. 1987, through September, 1988 (fiscal year 1988). Oil sample data only was supplied, not including feedback records; also excluded were oil sample records with Reason Sample Submitted code equal to *P* (Physical Test data), *A* (Accident/Incident data) and *J* (Equipment Failure data). These records are routinely excluded from the yearly baseline Wearmetal Frequency report issued for program managers. The two data tapes contained 956,339 records in total, each 165 bytes long.

Each 165 byte record describes a single oil analysis for a specific piece of equipment. The quantities identified in each record include

1. The laboratory, including the particular instrument, and the command to which it belongs.
2. The activity, home base code for the equipment sampled.
3. Type equipment code, identification of the type of equipment sampled.
4. Equipment serial number, identification of the specific individual sampled.
5. Date the sample was taken from the equipment.
6. Sequence number
7. Identification of whether the record contains oil analysis values or feedback information.
8. Date the sample was analysed.
9. Total time or miles since the equipment was last through overhaul.
10. Total time or miles since oil change.
11. Reason the sample was submitted.
12. Amount of oil added since the last sample.
13. Type of oil used in the equipment.
14. Response time required to analyze the sample.
15. Laboratory recommendation, based on the spectrometric analysis.

16. Spectrometric analysis readings, in whole parts per million, for up to 20 different contaminants. The particular contaminants tracked can vary from one equipment code to another.

Although not specified, the ordering of the records on the tape appears to be chronological, according to the date the data was received by SA-ALC during the period covered. The great majority of the dates listed for sample analyses were in fiscal year 1988 although some dates were listed as being several years earlier, perhaps through errors in data entry. The four-byte type equipment code (*TEC*) field contained a total of 705 different identifiers, indicating this number of different types of equipment being covered for the year. The number of analysis records available for these different equipment types varied considerably, as indicated in Table 1.

Table 1. Numbers of sample records for equipment codes (*TECs*).

Number of analyses	≤ 50	51–200	201–800	801–5,000	5,001–50,000	$> 50,000$
Number of *TECs*	471	120	56	33	18	7

As can be seen from this table, 471 *TECs* (more than $^2/_3$ of the total represented) had no more than 50 analyses reported to the data bank for the whole year; this count of analyses is over *all* serial numbers of the given *TEC*. Indeed, of these 471 with no more than 50 analyses, a full 142 had only one analysis for the year and 329 had no more than 10. Many of these extremely small yearly counts may be due to data-entry errors in entering the *TEC* codes. As can also be seen from Table 1, there were 7 *TECs* with more than 50,000 analyses recorded, which together account for 56% of all the records on the tapes; the largest number of analyses was reported for *TEC* DFKA, with 138,571 analyses, while *TEC* EPJA was identified with 97,112 analyses. Both of these are turbofan engines which together account for almost 25% of the analyses reported on the data tapes.

Consistency of Ranges

One goal of this study was to compare the consistency of the JOAP Laboratory Manual normal, marginal, high and abnormal ranges in the frequency counts actually observed for the different elements for operational engines, across various *TEC*s. To accomplish this, the data tape was first scanned to find the number of *TEC*s available, with the results already summarized in Table 1. A count was then made of the various engine serial numbers (*ESN*s) listed for each *TEC*, as well as a record of the number of analyses performed for each such *ESN*. A count was also made of the numbers of analyses reported from both types of spectrometers employed by the Air Force; atomic emission spectrometers produced 908,961 of the records (about 95% of the total) with atomic absorption spectrometers producing the remainder. Since it is well known that these two instruments do not produce identical ppm readings on the same sample, the reason that the JOAP Laboratory Manual includes separate ranges for the two, it is necessary to separate the records according to the instrument-type; thus the consistency of ranges can be (and is) examined separately for the two instruments.

As already mentioned, almost 25% of the records reported on the data tape were for the two turbo-fan *TEC*s DFKA and EPJA; both of these had fairly substantial numbers of readings for both instrument types and were included in the study. The two *TEC*s BSQA and BSPA identify turbo-jet engines (a total of 103,333 records between them, about 11% of all the records on the tapes) and also had large numbers of readings from both instrument types, so they were examined as well. The third, and final, type of engine available with sufficiently large numbers of records to examine (from both types of instrument) was the turbo-prop: *TEC*s LLDA and LLLA provided the largest numbers of records for the year (11,755 records between them), with both instrument types again fairly well represented. Thus, this study focusses attention on three engine types (turbo-fan, turbo-jet and turbo-prop) and employs data from two different *TEC*s for each of these types.

A number of tabular and graphical presentations of the data for these six *TEC*s have been prepared; for simplicity of exposition, only the tables and graphs for *TEC* DFKA, which has the most records, are presented in the main body of this report. Discussion is included for all six, with the supporting tables and graphs for the remaining five *TEC*s presented in the appendix.

It is desired, for this study, to examine the placement of the normal, marginal, high, and abnormal ranges within the distribution of contaminant readings for active, operational aircraft. To aid this goal, records with *T* (Test Cell), *K* (Prior to Maintenance–Removal), *M* (Post Maintenance Check), *P* (Physical Test) or *X* (Initial sample) listed in the *Reason Sample Submitted* field are excluded. In addition, the only *ESN*s utilized were those which contributed at least 40 analyses to the SA-ALC data bank in fiscal year 1988 (for *TEC*s DFKA, EPJA, BSQA, BSPA) and at least 20 analyses for the turbo-prop engines LLDA, LLLA. This lower number of analyses was used for the turbo-prop engines because there are considerably fewer analyses of this type of engine available; this lower number of analyses available is undoubtedly caused by a different sampling schedule and/or mode of use for aircraft employing this engine type.

Table 2. Equipment code DFKA, Atomic Emission

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–10	11–12	13–14	15 and over	0.0012
Count	125,893	68	12	65	
Ag	0–2		3	4 and over	0.0006
Count	125,921		16	64	
Al	0–10	11–12	13–14	15 and over	0.0001
Count	125,997	1	2	4	
Cr	0–4	5	6	7 and over	0.0001
Count	125,989	2	3	9	
Ni	0–4	5	6	7 and over	0.0040
Count	125,531	409	66	28	
Ti	0–10	11–12	13–14	15 and over	0.0004
Count	125,963	31	3	12	

Tables 2 and 3 provide counts of the records for *TEC* DFKA, which fall into the normal, marginal, high and abnormal ranges, for the two different instrument types. Note that fewer than four classes are used for some of the elements, indicated by no specified range or count (see Ag in Table 2, for example, and Ag, Cr, Ni in Table 3, where no marginal range is specified in the laboratory manual). The total number of records summarized may differ slightly from element to element, caused by missing data for some elements for some records. Also presented is the proportion of records *not* in the normal range (that is, those that are marginal, high or abnormal). From the counts (and proportions) summarized, it would appear that the placement of the normal, marginal, high and abnormal ranges are very conservative, in the sense that the great majority of records fall into the normal range; the summaries for the other 5 *TEC*s are given in the appendix and present similar results. While these proportions found outside the normal range are quite small (and not particularly uniform), there is reason to believe that they may in fact be smaller than indicated in these tables, as will be discussed in the section on non-normal records.

Frequency histograms have also been prepared, giving the proportions of ppm readings observed for these records, for the various elements, for both types of spectrometers. Figures 1 and 2 present these histograms for *TEC* DFKA, for the two spectrometer types; any proportion which is smaller than .005 is too small to appear in these figures. The number of records used in constructing the histograms is printed at the top; in each case this number of records describes the *last* (bottom-right) histogram in the figure. Since not every record used had values for

Table 3. Equipment code DFKA, Atomic Absorption

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–5	6	7	8 and over	0.0005
Count	2,105	0	1	0	
Ag	0		1	2 and over	0.0247
Count	2,054		51	1	
Al	0–6	7	8–9	10 and over	0.0019
Count	2,102	1	3	0	
Cr	0–1		2	3 and over	0.0000
Count	2,106		0	0	
Ni	0–1		2	3 and over	0.0033
Count	2,098		6	1	
Ti	0–6	7	8–9	10 and over	0.0000
Count	2,105	0	0	0	

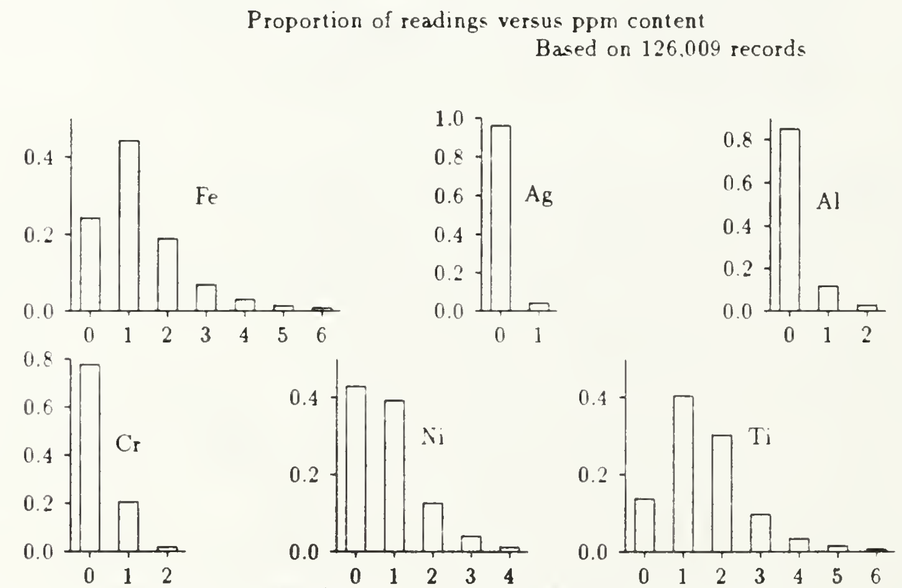

Figure 1. Equipment code DFKA, Atomic Emission

all elements, there is a (very) small variation in the numbers of counts represented in the histograms for the various elements (for the same *TEC*. These figures give an indication of the numbers of times the different ppm values occur, for the various elements, for both types of spectrometers; they also give a graphic indication of the fact that the atomic absorption readings are smaller than their emission counterparts. The appendix presents the same plots for the other five *TEC*s summarized.

In preparing the frequency histograms just discussed, it was noted that there appears to be a strong indication that the contaminant readings shift to higher

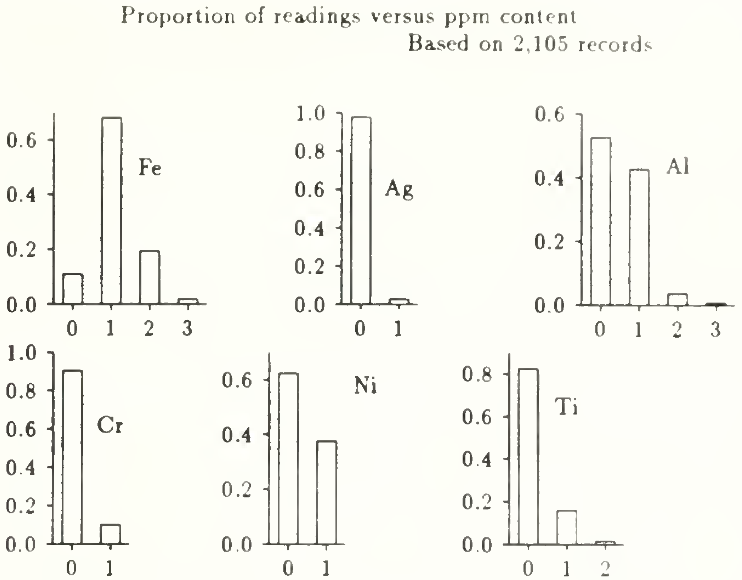

Figure 2. Equipment code DFKA, Atomic Absorption

values with increasing values for the hours since oil change; that is, as the oil in the system ages the contaminant buildups seem to increase. This phenomenon is described in figures 3 (for atomic emission) and 4 (for atomic absorption). Each of these figures presents two histograms, one for those records reporting no more than 200 hours since oil change and the other for more than 200 hours since oil change. The number of hours at which this break is made was chosen to give roughly equal numbers of readings on either side of the break, for both instrument types; this breakpoint differs from one *TEC* to another, as is evident from the figures presented in the appendix.

The unfilled bars give the proportions of readings for the fresher oil, while the filled bars give the proportions for the older oil; for every element (for DFKA) there is a noticeably higher proportion of readings for the higher ppm values. Indeed, even for element Ag in Figure 3, where the proportions of 0 and 1 values visually appear to be essentially equal, there is an extremely significant shift in a statistical sense, because of the very large sample sizes involved. This same general increase in ppm content occurs for most elements for the other *TEC*s examined (see the figures in the appendix). Such a shift to higher values, for larger values of hours since oil change, would seem to indicate that any ranges employed to delineate normal versus marginal, high or abnormal should also shift and not be static. This point is discussed further in the section SETTING RANGES.

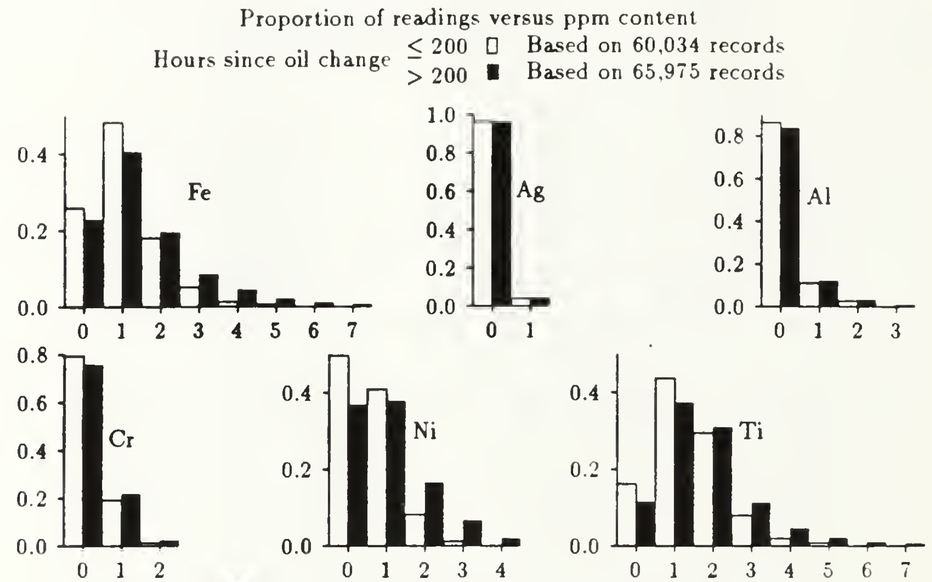

Figure 3. Equipment code DFKA, Atomic Emission

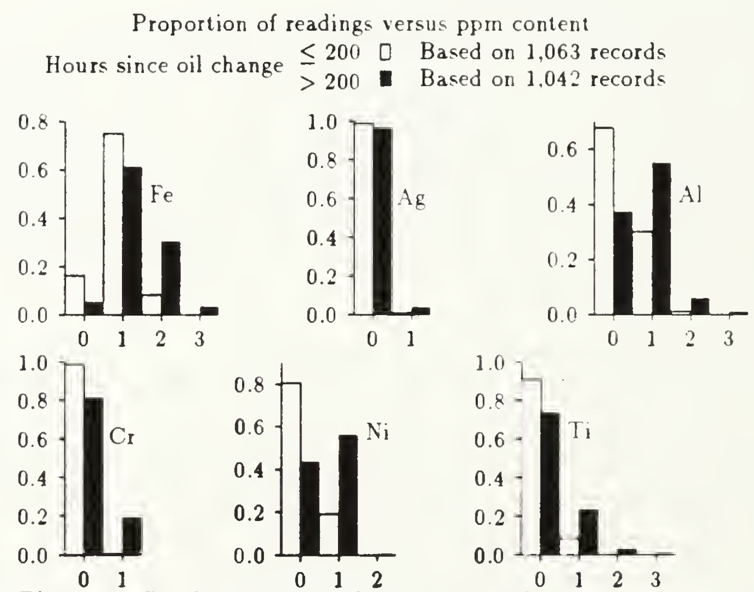

Figure 4. Equipment code DFKA, Atomic Absorption

Non-normal Records

Each oil analysis record on the data tapes includes a field which identifies the laboratory's recommendation for action to be taken, based on the results of the current spectrometer readings. Thus, it is possible to identify those records on which the laboratory made a recommendation for some special type of action, varying from requirements for sampling with greater frequency than usual to grounding of the aircraft for inspection or even requesting removal of an engine. This laboratory recommendation is to be derived from use of the decision guidance table given in the manual; this decision guidance table, in turn, requires use of two pieces of information, called the range value and the trend value (for each element monitored). The range value refers simply to the range into which the sample reading falls, the normal, marginal, high and abnormal ranges mentioned earlier. The trend value is to be computed by the operator (for each element); this number is the difference between the contaminant level found in this current sample and the level in the previous sample (for the same *ESN*), adjusted to a 10 hour flight period. These trend values are not reported to the data base at SA-ALC, and are not provided on the data tapes.

This decision guidance table provides a suggested laboratory recommendation based on the current range values, the previous sample's range values and the trend value. It uniformly recommends special action codes for any sample reading in the high or abnormal ranges, for any element, and suggests consideration of a special action code for any sample reading in the marginal range. The decision guidance table suggests an *A* recommendation ("No recommendation. Resume or continue routine sampling.") for samples whose current and previous ranges, and trend values, are normal; indeed it suggests consideration of an *A* recommendation for all samples whose current ranges are normal, regardless of the other quantities.

Table 4. Equipment code DFKA, Atomic Emission
Counts of records with
non-normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
Fe	1797	22	6	7
Ag	1823		8	1
Al	1830		2	
Cr	1830	2		
Ni	1764	41	23	4
Ti	1824	5	3	

To examine the records which contained non-normal recommendations, all records were deleted whose reason for taking the sample was *T*, *K*, *M*, *P* or *X*, as above; also deleted were those records whose laboratory recommendation code was *A* (No recommendation. Resume or continue routine sampling.), *D* (Unable to analyze sample as received. Submit resample ASAP.), *G* (Suspect contamination. Submit resample together with sample of new oil servicing this unit to the laboratory ASAP.), or *U*, *V* or *W* (codes used only for Navy units). The remaining records then presumably contain those for which the laboratory called for something other than continued routine sampling. The resulting counts of numbers of records with readings in the various ranges are presented in Table 4, for the atomic emission readings for DFKA, and in Table 5 for the atomic absorption readings for this same *TEC* (again, the same information for the other *TECs* is given in the appendix). It is interesting to compare these counts with the earlier values given in Tables 2 and 3 for *TEC* DFKA; note that Table 2 gives a count of 65 records (out of the total of 126,038) in the abnormal range for Fe. Recall as well that the decision guidance table suggests special action should be called for with any record in the abnormal range. Thus, one would expect to find 65 records in the non–normal category with abnormal Fe counts, rather than just 7 as indicated in Table 4. This phenomenon is quite apparent for all elements and ranges (and the other *TECs* as well, reported in the appendix). One possible explanation (thought to be unlikely) is that the operator did not choose to act on such abnormal range values; the more likely explanation is simply that data entry and/or reporting errors are responsible for inflating the counts in the earlier tables. Note as well, from Tables 4 and 5, that the great preponderance of contaminant readings for all elements fall into the normal range, rather than one of the higher ranges which would flag special action. Granted that the spectrometric laboratory recommendation is based only on their oil analysis records, and the Laboratory Manual decision guidance table, it seems apparent that the trend calculation (not reported on the data tapes) must be the cause of almost all non–normal recommendations issued (for the *TECs* examined).

Table 5. Equipment code DFKA, Atomic Absorption

Counts of records with

non–normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
Fe	47			
Ag	47			
Al	43	1	3	
Cr	47			
Ni	47			
Ti	47			

Consistency Conclusions

From Tables 2 and 3, and those presented for the other five *TECs* in the appendix, there appears to be wide variations in the placements of the normal, marginal, high and abnormal ranges across elements, for all *TECs*. However, granted the inconsistencies found in the counts as mentioned above, it is not feasible to really make any such comparisons with the data available; any and all of the differences found in locations of the ranges may be totally caused by data entry errors, which are not possible to identify from the data provided.

In spite of the inconsistencies or data–entry errors already noted, it seems clear that the normal, marginal, high and abnormal ranges employed (for the *TEC*s examined) are extremely conservative; that is, the great preponderance of counts observed fall into the normal range. This could be caused by an excessively large normal range being listed in the Laboratory Manual. In any system which employs analytic data for diagnostic purposes, there are two types of errors which could occur:

i. Requesting special action when it is not in fact needed.

ii. Not requesting special action when in fact it may be necessary (and could lead to loss of life and equipment).

As the "normal" range is lowered, the probability of occurrence of this first type of error necessarily increases while the probability of occurrence of the second type of error necessarily decreases. The actual values for these probabilities of error are not known, but this general behavior must occur. Thus, an excessively large normal range will help to avoid calling for special action when it is not needed, but runs the risk of allowing the second type of error to occur. Great care is needed in setting the normal range to properly balance these quantities.

Returning to Tables 2 and 3 (which admittedly appear to be affected by data-entry/recording errors) there is a large disparity in the proportions of non–normal records from one element to another. *If* this phenomenon is real (and not just caused by data errors), it does not seem desirable; that is, granted one had perfectly clean data, and a very large sample of records, it would seem ideal that the proportions of non–normal records should be at least roughly the same across elements (whether its value may be .001 or .0001 or whatever). Variation in this proportion across elements would seem to indicate that one is willing to take bigger risks with Fe, say, than with Ag, which may not be reasonable.

If it is desired to continue employing the current type of system, that is one in which tables of normal, marginal, high and abnormal limits are published for *TEC*s to apply for all such *ESN*s, it is recommended that the limits employed be reviewed, and possibly revised, yearly. When a new *TEC* enters the inventory the initial limits could be determined by those employed for the "most similar" currently employed *TEC*. As actual oil analysis records are accumulated for the new *TEC*, say once a total of 10,000 analyses have been recorded (ideally without error), one could then construct relative frequency histograms of the type discussed in this report for each element of interest and review the performance of the ranges employed. The most logical variables to examine in such a review are the proportions of records which fall into the four ranges (if four are used) for each of the elements monitored; as discussed above, it would seem on the surface desirable to have these proportions at least roughly equal for all elements; the actual magnitudes of the proportions should also be reviewed, since they have a bearing on the probabilities of committing the two types of error discussed above. Proportions of .999, .0005, .0003 and .0002 might serve well for the classes normal, marginal, high and abnormal; since the engine manager bears responsibility for his *TEC* the actual decision for setting these proportions must be his and should include serious consideration of the two types of error already mentioned.

The current guidance for making laboratory recommendations, based on spectrometric oil analysis records, suggests decisions should be driven only by the current and next-previous range values for the elements monitored, and the computed trend values for these elements. Decision guidance tables are provided as an aid in arriving at the recommendation made, based on these quantities, regardless of the number of hours since the oil has been changed. In spite of the inconsistencies of counts already pointed out, it appears that there is a definite tendency for the ppm counts observed to increase with the number of hours since oil change; if this phenomenon is real, the values used to define the normal, marginal, high and abnormal ranges should also possibly shift with the number of hours since oil change.

Reference [2] describes a system employed with the Air Force *CEMS-IV* program which has distinct advantages in monitoring oil analysis records, granted modern computing power is available. First, since it is computer-based, it is capable of doing much more sophisticated computations than one could expect from a laboratory technician and can take advantage of more available information beyond just the current and next-previous readings for a given *ESN*. Second, it makes use of the number of hours since the oil was changed, for the sample submitted; the recommendation produced can shift with this variable if that seems appropriate (and will not shift if not appropriate). Third, its recommendation is based on the behavior of the particular *ESN* from which the sample was drawn; it does not depend simply on static tables which are the same for all *ESN*s with the same *TEC*. This behavior seems quite consistent with the On Condition Maintenance philosophy which is currently popular. It is recommended that the type of procedure described in this reference be seriously considered for implementation at any laboratory with the requisite computing equipment.

References

[1] JOINT OIL ANALYSIS PROGRAM LABORATORY MANUAL N00600-76-D-0596, 1 March 1978 with Change 2 - 15 April 1981 (and later corrections).

[2] Larson, H. J. and Jayachandran, T. *The CEMS-IV OAP Algorithm* NAVAL POSTGRADUATE SCHOOL Technical Report NPS55-83-013, May 1983.

Appendix

This appendix presents the supporting tables and graphs for the 5 other *TEC*s discussed in the attached report; *TEC* EPJA is a turbo-fan engine (as is DFKA), while *TEC*s BSQA and BSPA are both turbo-jet engines and *TEC*s LLDA and LLLA are turbo-prop engines. Four graphs and four tables are presented for each of these *TEC*s, corresponding to those presented earlier for DFKA. The graphs presented give proportions of readings from the tapes which contained the various (whole) ppm values for each of the elements monitored, overall, for both types of instrument; also presented are pairs of histograms illustrating the shift to higher counts for those engines with larger values for hours since oil change.

The tables presented give the number of reported records to fall into the four ranges of normal, marginal, high and abnormal contents, for both instrument types, as well as the counts made from the actual non-normal records. As with *TEC* DFKA, there appears to be a major problem with data entry errors, or some other phenomenon, which causes inconsistencies in these types of count. The tables and graphs are organized into groups according to type of engine and *TEC*.

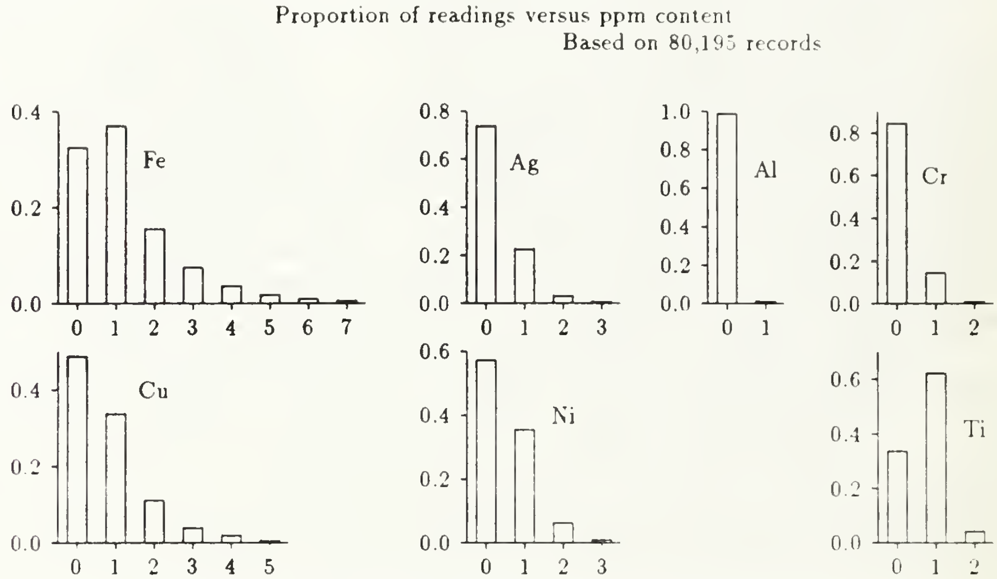

Figure A1. Equipment code EPJA, Atomic Emission

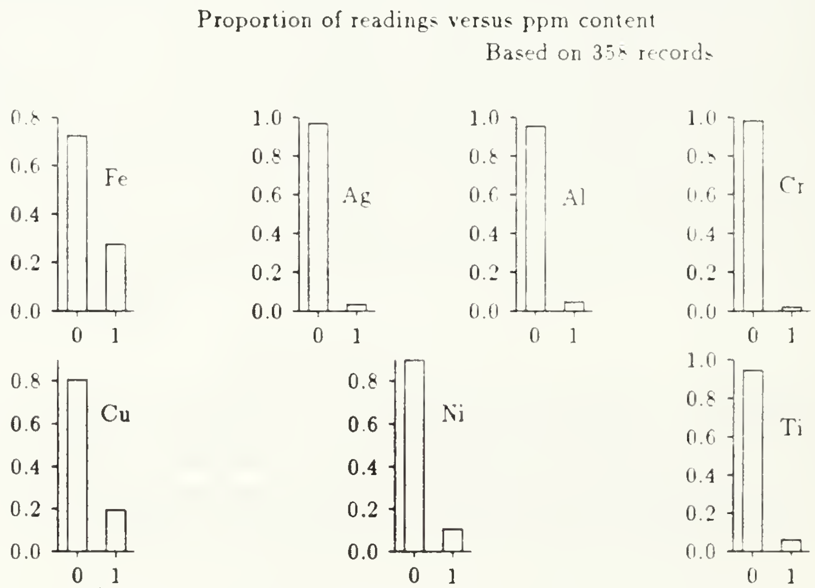

Figure A2. Equipment code EPJA, Atomic Absorption

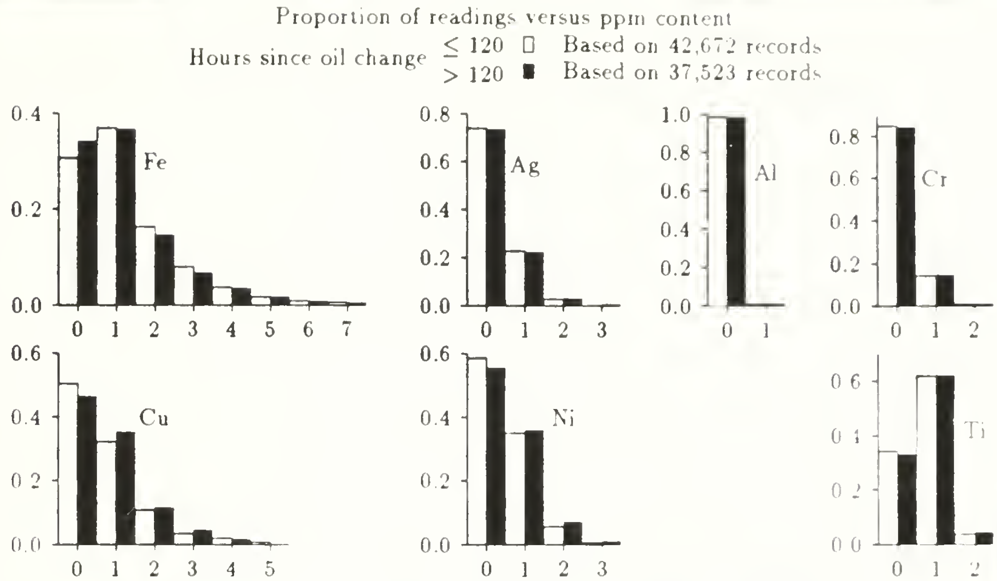

Figure A3. Equipment code EPJA, Atomic Emission

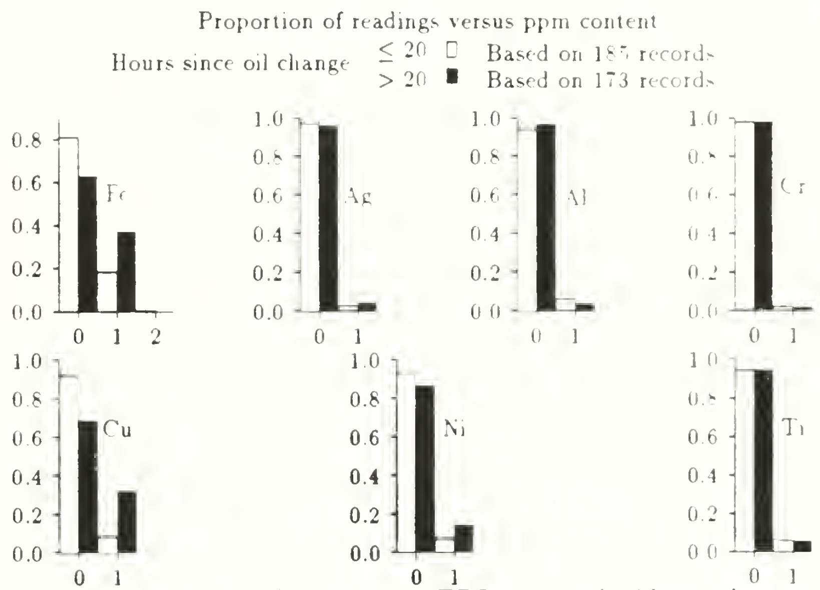

Figure A4. Equipment code EPJA, Atomic Absorption

Table A1. Equipment code EPJA, Atomic Emission

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–9	10–13	14–17	18 and over	0.0029
Count	80,193	186	25	24	
Ag	0–3		4	5 and over	0.0020
Count	80,184		129	34	
Al	0–3		4	5 and over	0.0004
Count	80,394		2	29	
Cr	0–3		4	5 and over	0.0004
Count	80,393		22	8	
Cu	0–10	11–14	15–17	18 and over	0.0001
Count	80,410	0	0	9	
Ni	0–5	6–7	8–9	10 and over	0.0003
Count	80,246	19	1	5	
Ti	0–5	6	7–8	9 and over	0.0001
Count	80,185	3	2	5	

Table A3. Equipment code EPJA, Atomic Emission

Counts of records with

non–normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
Fe	771	72	24	6
Ag	864		5	4
Al	868		2	3
Cr	860		12	1
Cu	873			
Ni	862	11	1	
Ti	867	3		3

Table A2. Equipment code EPJA, Atomic Absorption

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–5	6	7	8 and over	0.0000
Count	358	0	0	0	
Ag	0–3		4	5 and over	0.0000
Count	358		0	0	
Al	0–3		4	5 and over	0.0000
Count	358		0	0	
Cr	0–3		4	5 and over	0.0000
Count	358		0	0	
Cu	0–4	5–6	7	8 and over	0.0000
Count	354	0	0	0	
Ni	0–3	4	5	6 and over	0.0000
Count	358	0	0	0	
Ti	0–2		3	4 and over	0.0000
Count	358		0	0	

Table A4. Equipment code EPJA, Atomic Absorption

Counts of records with

non–normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
There were no non-normal recommendations made.				

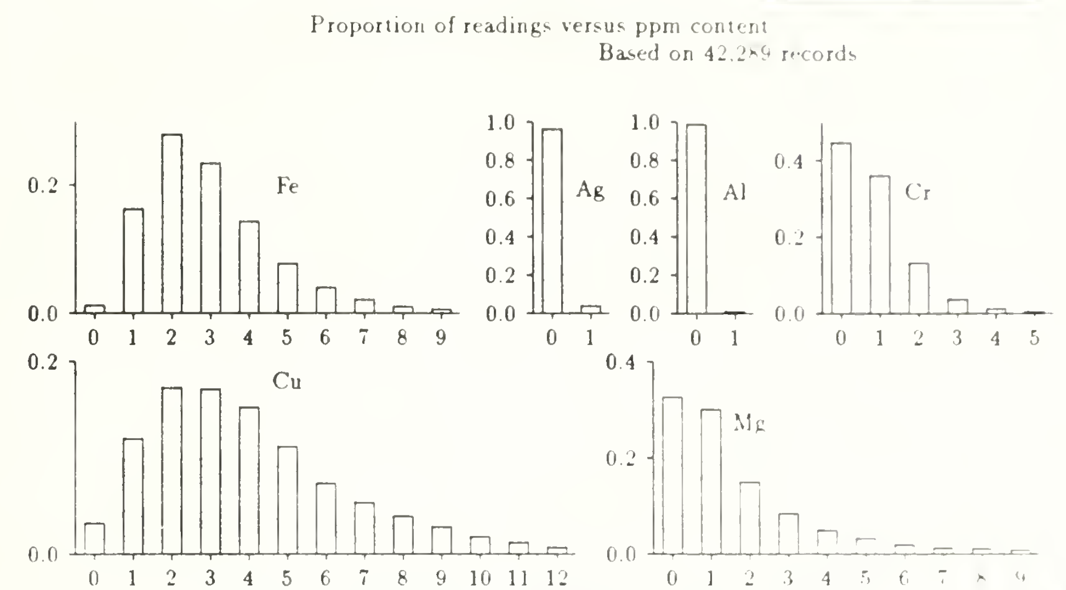

Figure A5. Equipment code BSQA. Atomic Emission

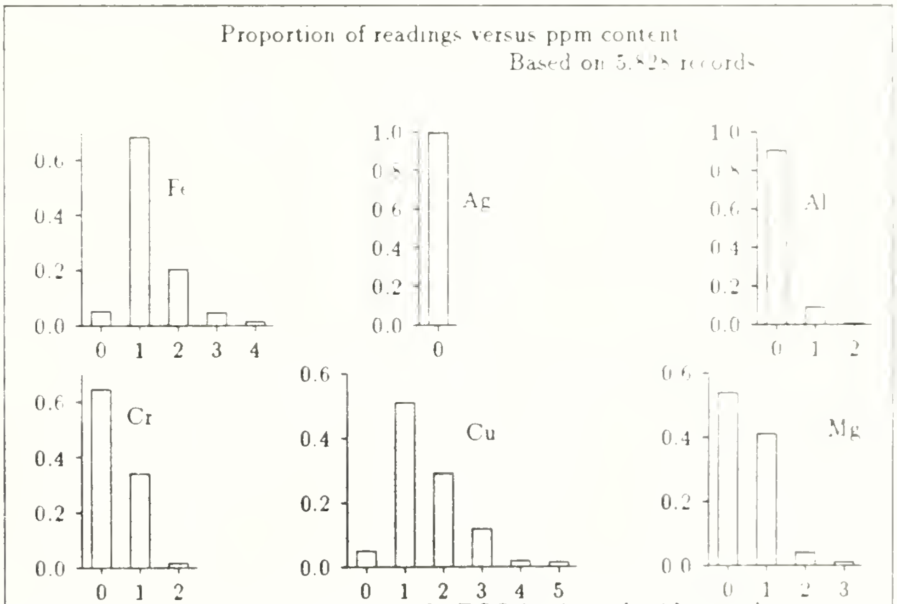

Figure A6. Equipment code BSQA, Atomic Absorption

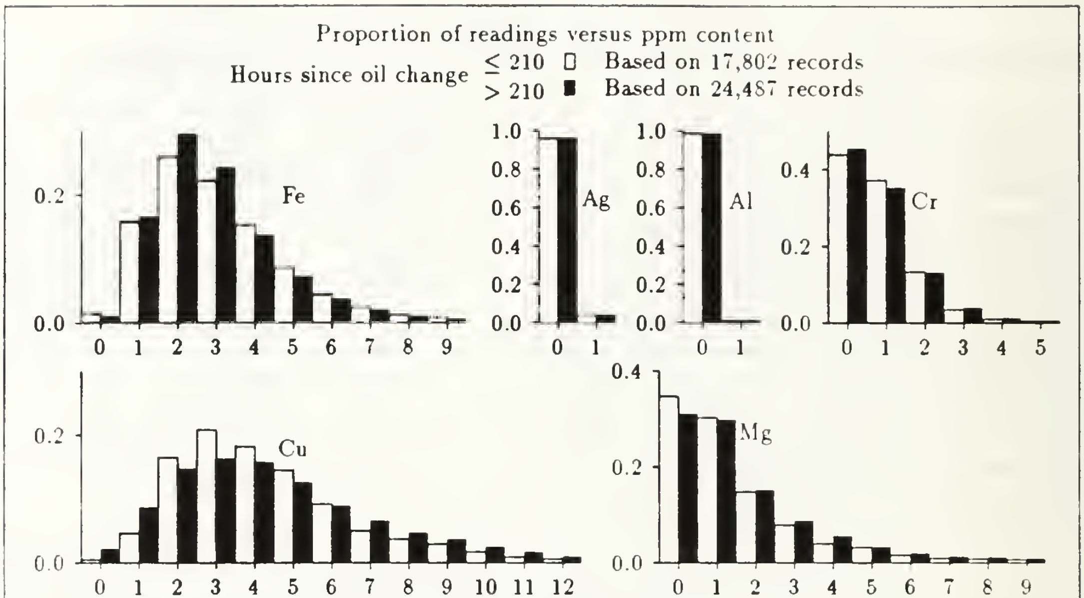

Figure A7. Equipment code BSQA, Atomic Emission

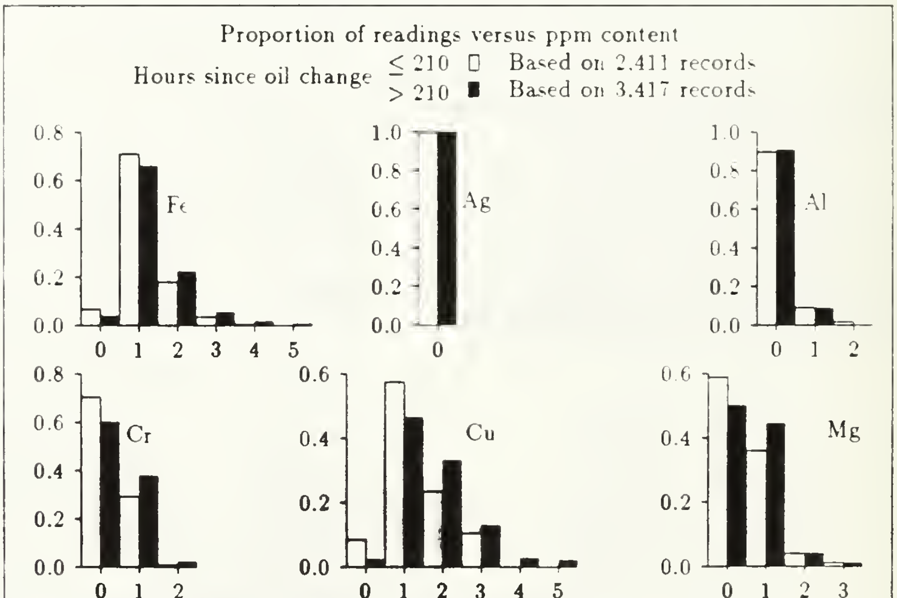

Figure A8. Equipment code BSQA, Atomic Absorption

Table A5. Equipment code BSQA, Atomic Emission

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–29	30–36	37–44	45 and over	0.0009
Count	42,251	17	5	16	
Ag	0–3	4	5	6 and over	0.0005
Count	42,267	1	0	21	
Al	0–8	9	10–11	12 and over	0.0001
Count	42,285	1	2	1	
Cr	0–10	11–12	13–14	15 and over	0.0003
Count	42,276	2	1	10	
Cu	0–18	19–22	23–27	28 and over	0.0008
Count	42,256	7	0	26	
Mg	0–14	15–17	18–21	22 and over	0.0011
Count	42,244	23	6	16	

Table A7. Equipment code BSQA, Atomic Emission

Counts of records with

non-normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
Fe	308	7	3	1
Ag	319			
Al	318	1		
Cr	319			
Cu	315	1	3	
Mg	319			

Table A6. Equipment code BSQA, Atomic Absorption

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–14	15–18	19–23	24 and over	0.0000
Count	5,828	0	0	0	
Ag	0–1		2	3 and over	0.0009
Count	5,823		3	2	
Al	0–2		3	4 and over	0.0009
Count	5,823		5	0	
Cr	0–5	6	7	8 and over	0.0002
Count	5,827	0	0	1	
Cu	0–7	8–9	10	11 and over	0.0000
Count	5,828	0	0	0	
Mg	0–7	8–9	10	11 and over	0.0000
Count	5,828	0	0	0	

Table A8. Equipment code BSQA, Atomic Absorption

Counts of records with

non-normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
Fe	14			
Ag	14			
Al	14			
Cr	14			
Cu	14			
Mg	14			

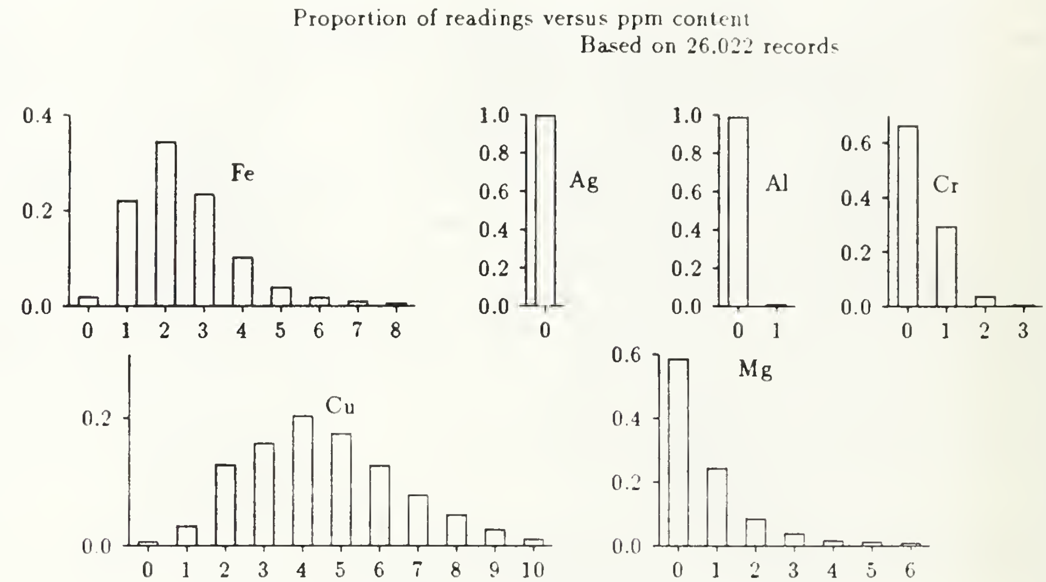

Figure A9. Equipment code BSPA, Atomic Emission

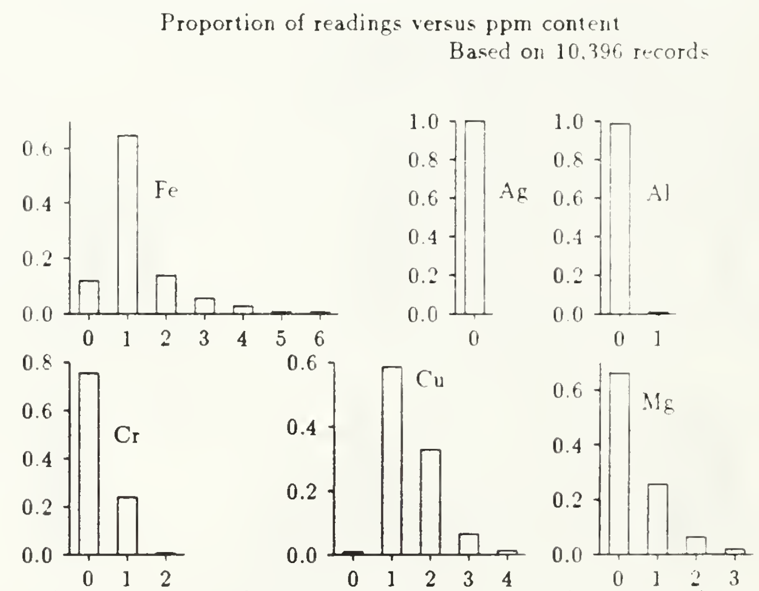

Figure A10. Equipment code BSPA, Atomic Absorption

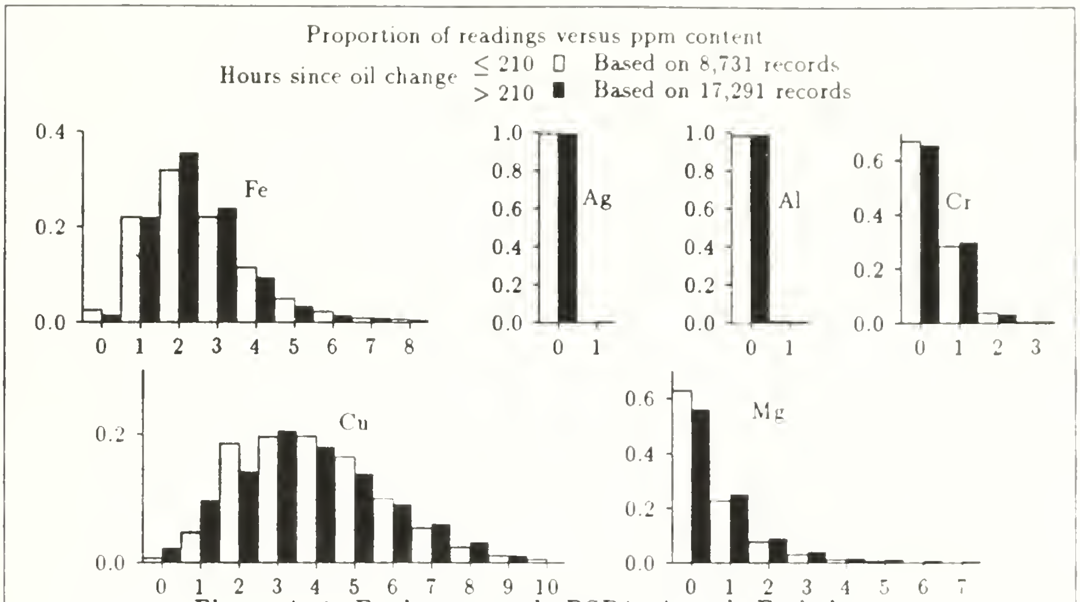

Figure A11. Equipment code BSPA. Atomic Emission

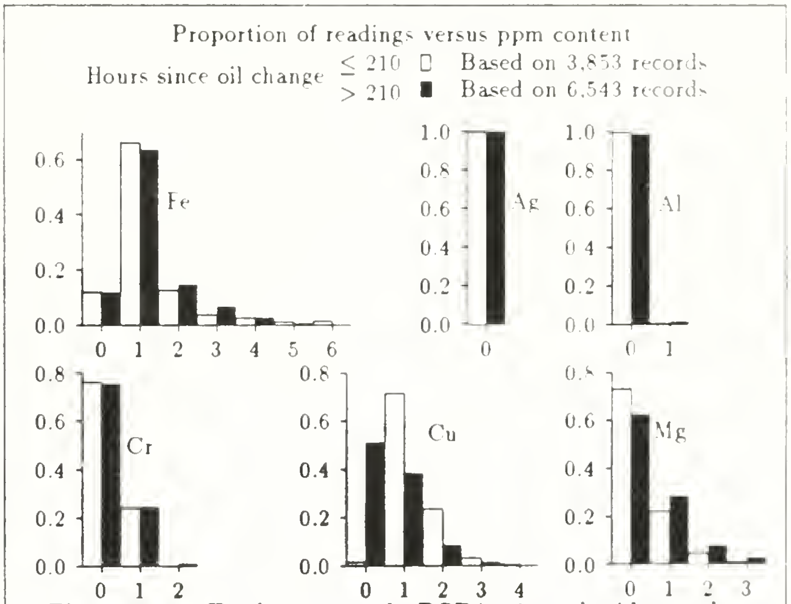

Figure A12. Equipment code BSPA, Atomic Absorption

Table A9. Equipment code BSPA, Atomic Emission

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–29	30–36	37–44	45 and over	0.0011
Count	25,996	10	7	12	
Ag	0–3	4	5	6 and over	0.0005
Count	26,011	2	1	9	
Al	0–8	9	10–11	12 and over	0.0001
Count	26,023	0	2	0	
Cr	0–10	11–12	13–14	15 and over	0.0002
Count	26,021	1	1	2	
Cu	0–18	19–22	23–27	28 and over	0.0015
Count	25,984	23	6	10	
Mg	0–14	15–17	18–21	22 and over	0.0010
Count	25,996	10	6	10	

Table A11. Equipment code BSPA, Atomic Emission
Counts of records with
non-normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
Fe	248	2		
Ag	249		1	
Al	249		1	
Cr	250			
Cu	244	4	2	
Mg	246	2	2	

Table A10. Equipment code BSPA, Atomic Absorption

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–14	15–18	19–23	24 and over	0.0004
Count	10,392	0	0	4	
Ag	0–1		2	3 and over	0.0003
Count	10,393		0	3	
Al	0–2		3	4 and over	0.0004
Count	10,392		2	2	
Cr	0–5	6	7	8 and over	0.0002
Count	10,394	0	0	2	
Cu	0–7	8–9	10	11 and over	0.0010
Count	10,386	1	2	7	
Mg	0–7	8–9	10	11 and over	0.0007
Count	10,389	0	0	7	

Table A12. Equipment code BSPA, Atomic Absorption
Counts of records with
non-normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
Fe	46			
Ag	46			
Al	45		1	
Cr	46			
Cu	42	1	2	1
Mg	46			

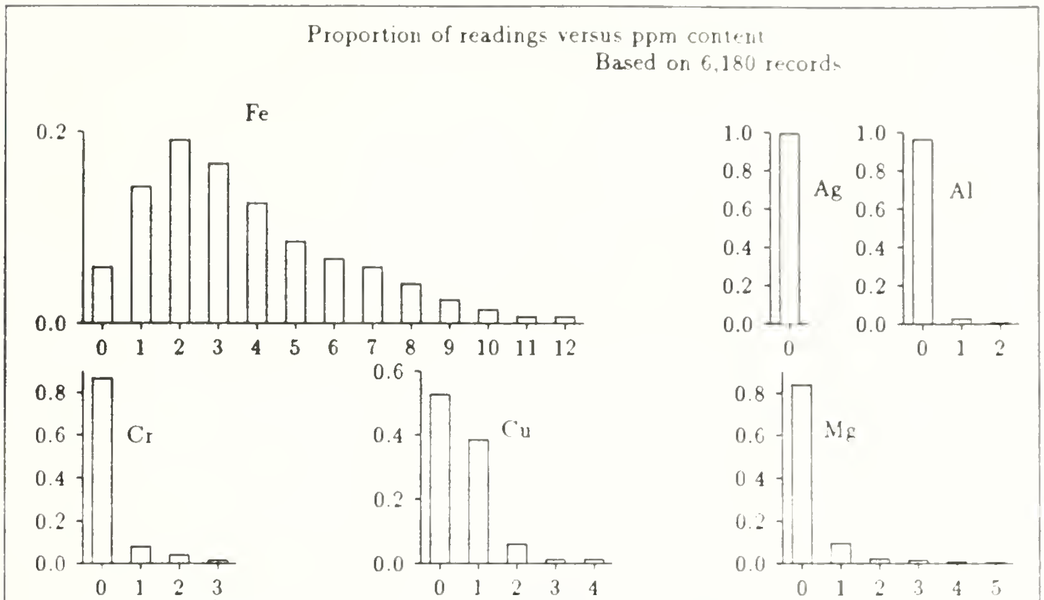

Figure A13. Equipment code LLDA, Atomic Emission

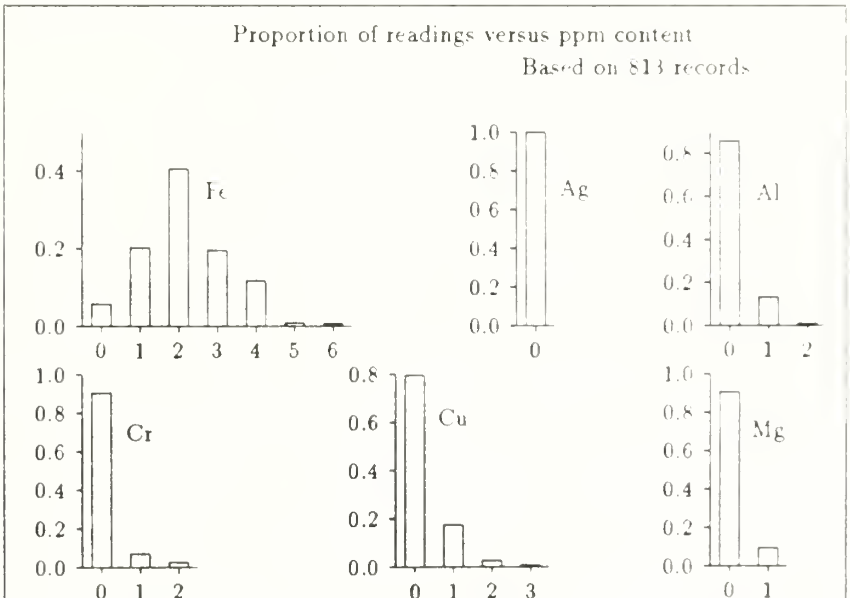

Figure A14. Equipment code LLDA, Atomic Absorption

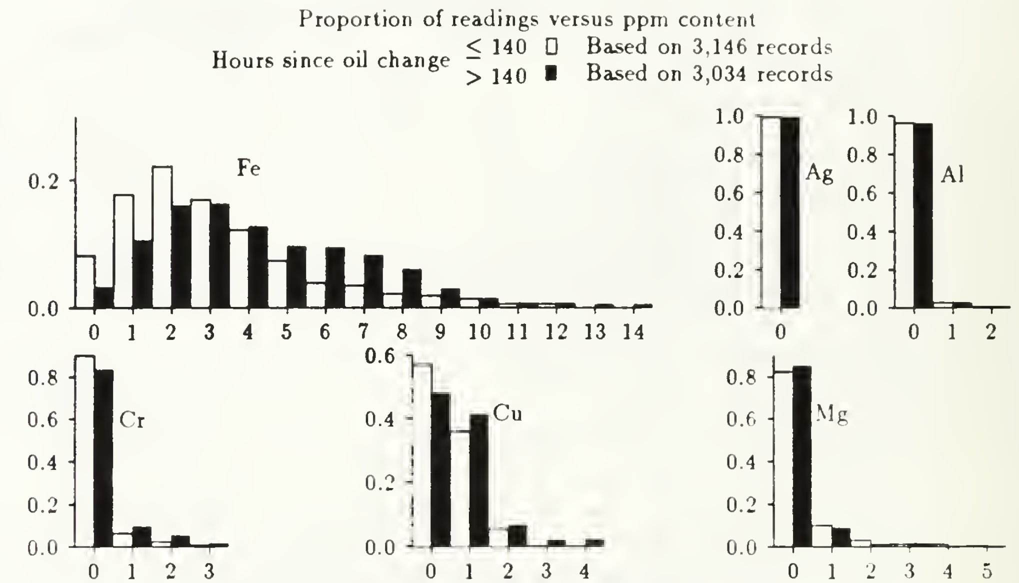

Figure A15. Equipment code LLDA, Atomic Emission

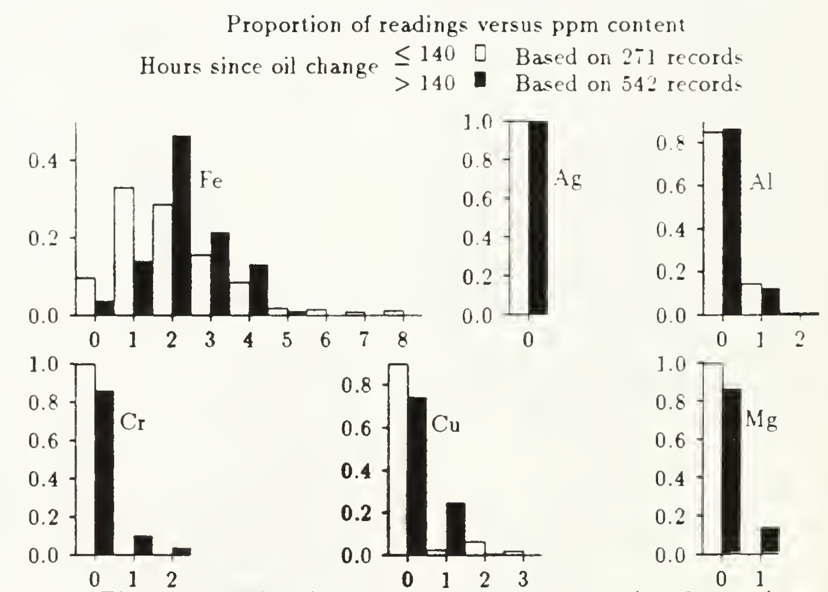

Figure A16. Equipment code LLDA, Atomic Absorption

Table A13. Equipment code LLDA, Atomic Emission

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–14	15–17	18–21	22 and over	0.0083
Count	6,130	33	9	9	
Ag	0–3		4	5 and over	0.0031
Count	6,163		0	19	
Al	0–10	11–12	13–14	15 and over	0.0002
Count	6,181	0	0	1	
Cr	0–3		4	5 and over	0.0026
Count	6,165		11	5	
Cu	0–8	9	10–11	12 and over	0.0011
Count	6,174	0	3	4	
Mg	0–8	9–10	11–12	13 and over	0.0068
Count	6,138	20	16	6	

Table A15. Equipment code LLDA, Atomic Emission

Counts of records with

non-normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
Fe	151	6	5	
Ag	162			
Al	162			
Cr	160		2	
Cu	160			2
Mg	157	1	2	2

Table A14. Equipment code LLDA, Atomic Absorption

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–7	8–9	10	11 and over	0.0086
Count	806	6	0	1	
Ag	0–1		2	3 and over	0.0000
Count	813		0	0	
Al	0–4	5	6	7 and over	0.0000
Count	813	0	0	0	
Cr	0–1		2	3 and over	0.0271
Count	791		21	1	
Cu	0–3		4	5 and over	0.0000
Count	813		0	0	
Mg	0–3	4	5	6 and over	0.0000
Count	813	0	0	0	

Table A16. Equipment code LLDA, Atomic Absorption

Counts of records with

non-normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
Fe	7	3	3	1
Ag	14			
Al	14			
Cr	14			
Cu	14			
Mg	14			

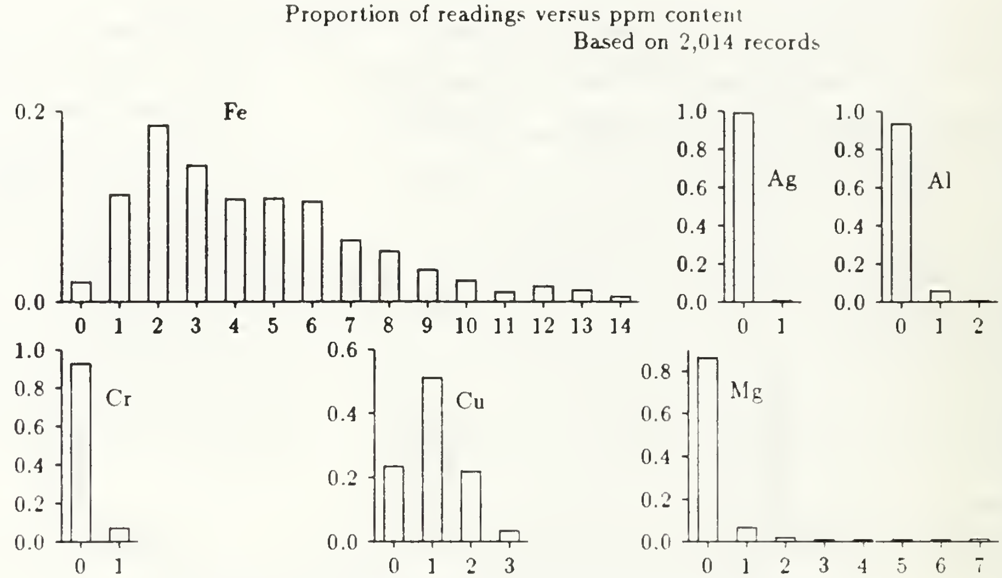

Figure A17. Equipment code LLLA. Atomic Emission

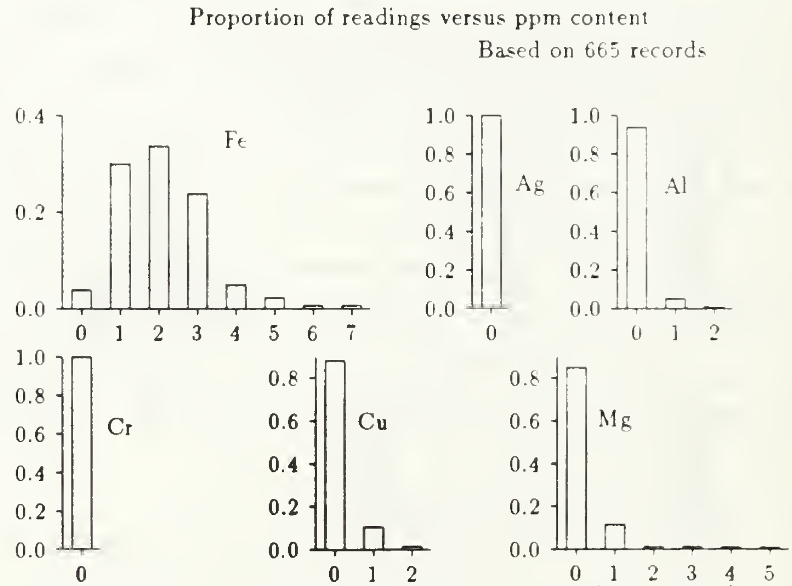

Figure A18. Equipment code LLLA. Atomic Absorption

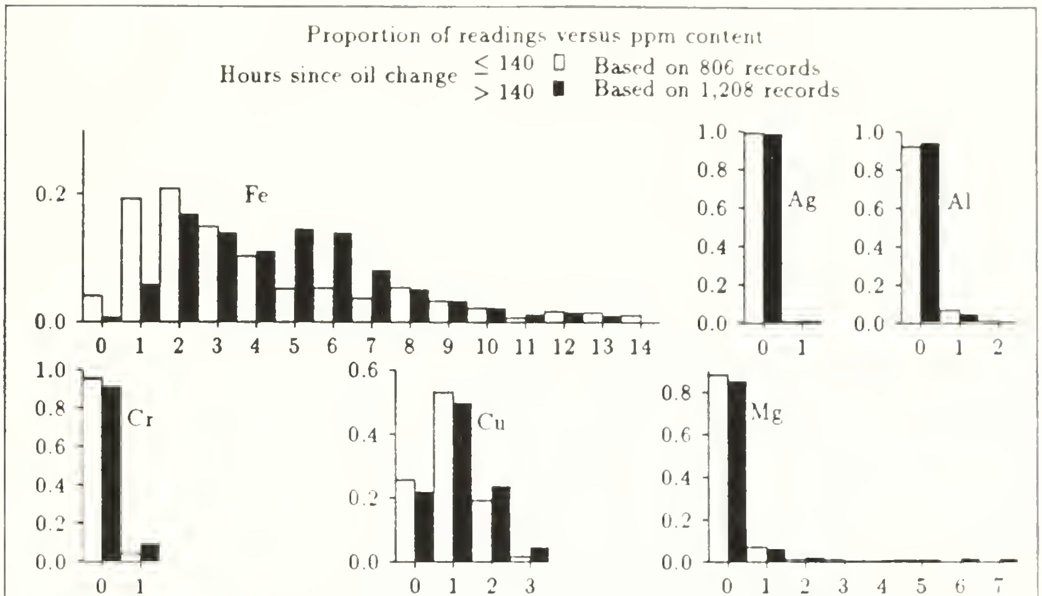

Figure A19. Equipment code LLLA. Atomic Emission

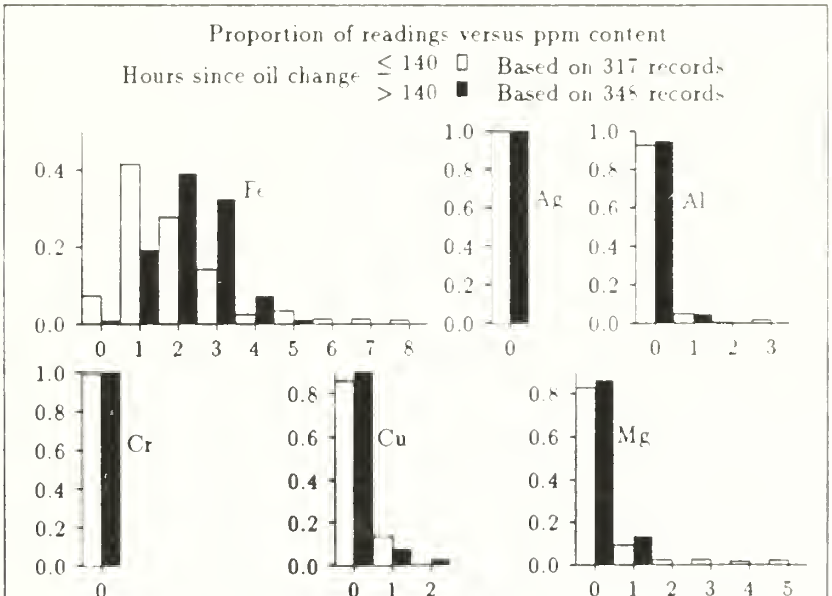

Figure A20. Equipment code LLLA. Atomic Absorption

Table A17. Equipment code LLLA, Atomic Emission

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–14	15–17	18–21	22 and over	0.0015
Count	2,011	3	0	0	
Ag	0–3		4	5 and over	0.0010
Count	2,012		0	2	
Al	0–10	11–12	13–14	15 and over	0.0000
Count	2,014	0	0	0	
Cr	0–3		4	5 and over	0.0000
Count	2,014		0	0	
Cu	0–8	9	10–11	12 and over	0.0000
Count	2,014	0	0	0	
Mg	0–8	9–10	11–12	13 and over	0.0020
Count	2,010	4	0	0	

Table A19. Equipment code LLLA, Atomic Emission

Counts of records with

non-normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
Fe	28			
Ag	28			
Al	28			
Cr	28			
Cu	28			
Mg	28			

Table A18. Equipment code LLLA, Atomic Absorption

Element	Normal range	Marginal range	High range	Abnormal range	Proportion not normal
Fe	0–7	8	9–10	11 and over	0.0045
Count	663	3	0	0	
Ag	0–1		2	3 and over	0.0000
Count	666		0	0	
Al	0–4	5	6	7 and over	0.0000
Count	666	0	0	0	
Cr	0–1		2	3 and over	0.0000
Count	666		0	0	
Cu	0–3		4	5 and over	0.0000
Count	666		0	0	
Mg	0–3	4	5	6 and over	0.0165
Count	654	5	6	0	

Table A20. Equipment code LLLA, Atomic Absorption

Counts of records with

non-normal laboratory recommendations

Element	Normal range	Marginal range	High range	Abnormal range
Fe	6	3		
Ag	9			
Al	9			
Cr	9			
Cu	9			
Mg	3	4	2	

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